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A MODEL CLIMATOLOGY OF THE OCEANIC THERMAL STRUCTURE AS APPLIED TO SINGLE STATION ANALYSIS

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INFORMAL MANUSCRIPT

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ABSTRACT

A model of the seasonal thermocline is presented. The model, based on parameters deduced from climatic data from ocean stations located in the Subarctic domain (north of the Gulf Stream-North Atlantic Current system), describes the onset, growth, and decay of the seasonal thermocline. However, owing to lack of data below 400 feet, the model does not delineate the convective layer in mid-winter. Temporal changes in temperature gradients above, within, and below the thermocline are discussed.

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John F. Ropek
Division Director

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I. INTRODUCTION

In discussing thermal structure characteristics of the ocean, the problem of defining the elements of the "normal" structure arises. By analogy with meteorology, the normal thermal structure is envisioned as a climatic entity dependent on time series data covering a period of years -- the longer the period, the closer the approach to climatological normals.

The normal thermal structure may be prepared from average data for increments of time and depth. Charts showing isotherms as a function of depth and time are an example of this type of climatology. Analogous climatic data would include mean temperatures at given times and/or heights above sea level in the atmosphere.

An operational climatology concentrates on presentation of data concerning parameters of the structure being described. For example, the mean height of the tropopause describes an operational parameter of the climatology of single-station analysis for that one station. An operational climatology of the oceanic thermal structure is based on parameters peculiar to the oceanic regime. One of the most interesting of these parameters is the seasonal thermocline produced by solar heating.

Before the establishment of ocean weather stations (OWS) in 1944, a description of the normal climatology of the thermal structure at any ocean location was impossible because the thermal structure was not regularly sampled at any location.

Since 1944, however, the bathythermograph (BT) has been used extensively as a means of gathering routine data between the surface and a depth of 450 feet at ocean station locations.

Historical BT data from the North Atlantic Ocean stations are now available to the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) in digitized form on magnetic tape. Computer programs have been written to define mean values of the principal parameters of the thermal structure (such as mean temperature, depth of the top of the thermocline, depth of the bottom of the thermocline, etc.). The environment around OWS ECHO (35°N, 48°W) has recently been analyzed.*

Present climatic data generally terminate at 400 feet, because the volume of 900-foot BT data is inadequate for meaningful computation. In recent years however, an increasing volume of 900-foot BT observations and some 1,350-foot electronic BT observations has been added to the tape file. It is only a matter of time until parameters can be described to these depths.

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*U. S. Naval Oceanographic Office. Statistical Analysis of the Thermal Structure at Ocean Weather Station ECHO, by J. B. Hazelworth. Technical Report No. 146, ASWEPS Report No. 8, July 1964.

II. THE LIFE CYCLE OF THE SEASONAL THERMOCLINE

The operational single-station climatology of the oceanic thermal structure will contain a description of the onset, growth, and disappearance of the seasonal thermocline. This physical phenomenon is indeed the major one that can be described with existing subsurface data, since data at depths below 400 feet are usually inadequate for describing fully the climatic mixed layer that extends to depths of 800 or 1,000 feet.

Figure 1 shows a model for the seasonal thermocline in the North Atlantic Ocean between 52° and 56°N. This figure has been synthesized from data of two ocean weather stations: BRAVO (56°N, 51°30'W) and CHARLIE (52°30'N, 35°W). The seasonal thermocline forms in oceanic spring when solar heat begins to be absorbed in the layers near the surface. The thermocline does not form at the surface but at a level apparently between 100 and 200 feet below the surface of the ocean. At the time of formation, the vertical gradient of temperature (that is, the decrease of temperature with increasing depth) is almost the same in the thermocline as in the layers above and below it. After formation, the thermocline grows rapidly in thickness and also in gradient of temperature as more and more heat is absorbed in the thermocline and the vertical diffusion of heat is slowed by the gradients.

The growth in thickness of the thermocline continues until a maximum is reached about 1 August. The thickness decreases thereafter until the time when vertical convection caused by heat loss virtually wipes out the seasonal thermocline. The bottom of the thermocline usually deepens gradually throughout the summer owing to conduction of heat from above, reaching maximum depth at the time when the thermocline disappears, usually at a depth between 200 and 300 feet.

III. THERMAL GRADIENTS

Three gradients of temperature are of interest: (a) gradient in the surface layer, or layer between the surface and the top of the thermocline; (b) gradient within the thermocline; and (c) gradient below the thermocline, formally described as that between the bottom of the thermocline and 400 feet because that is the extent of present climatic data. The model gradients, corresponding to the thermocline in figure 1, are shown in figure 2.

The gradient in the surface layer gradually increases to a maximum in early August just prior to the time of maximum surface temperature (mid- or late August). After the maximum temperature is reached, the gradient decreases because of heat loss in the surface layer; the decrease may be abrupt.

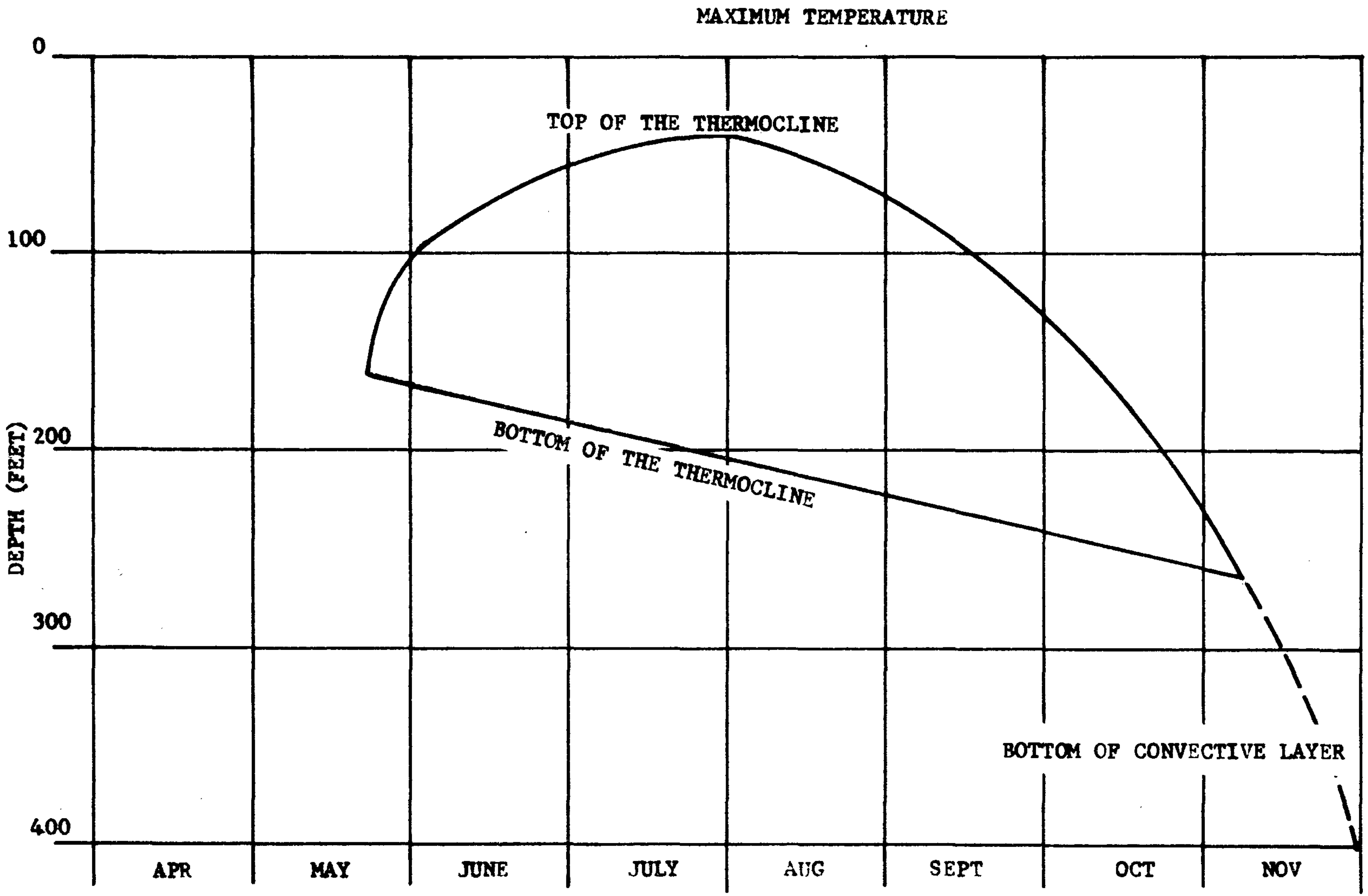

FIGURE 1. MODEL THERMOCLINE (52° to 56°N -- SUBARCTIC DOMAIN)

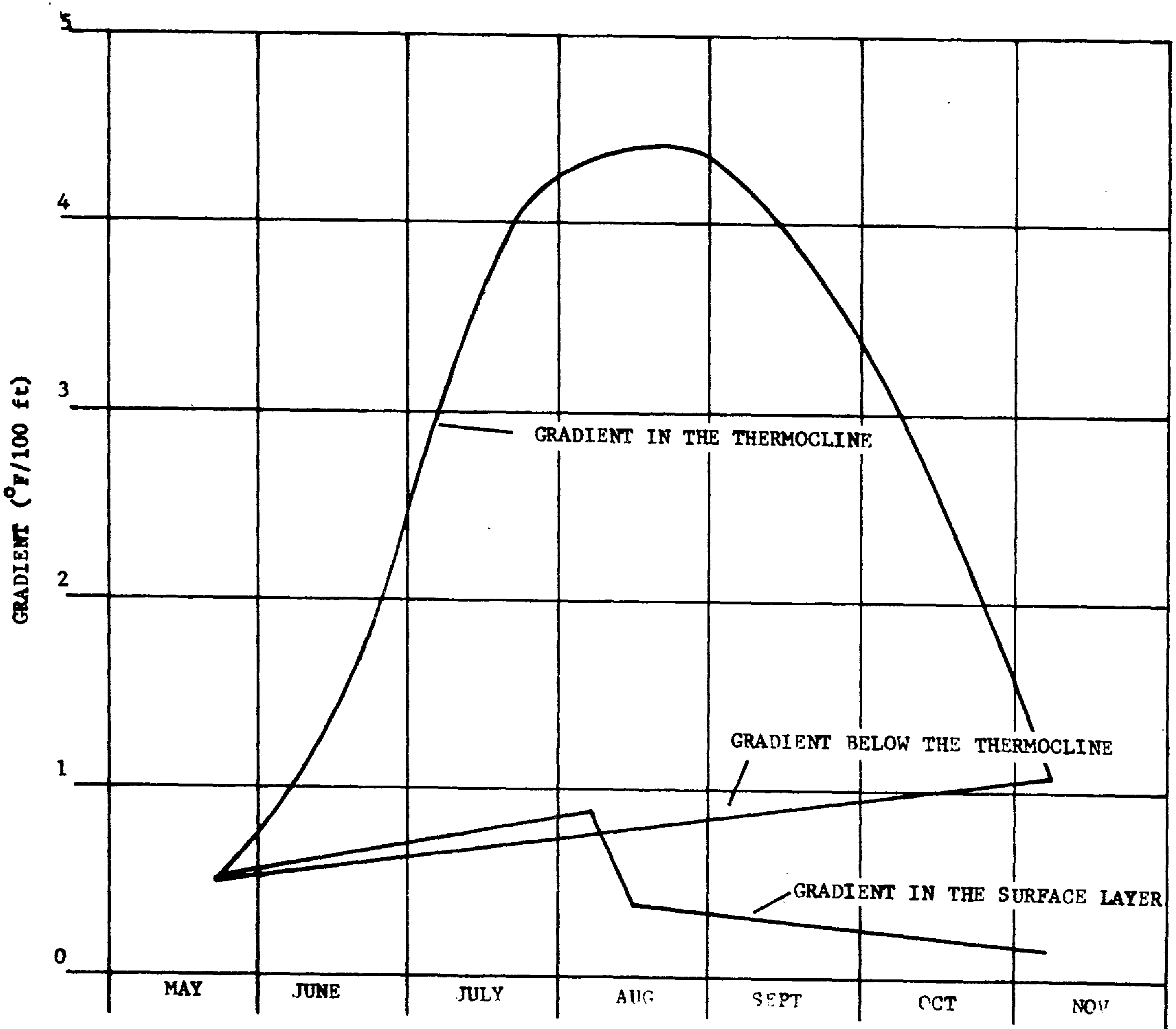

FIGURE 2. MODEL GRADIENTS IN THE THERMAL STRUCTURE

The gradient within the thermocline rises to a peak nearly simultaneously with the time of maximum surface temperature and falls thereafter as the thermocline thickness decreases. The gradient below the thermocline increases gradually throughout the lifetime of the thermocline.

IV. THE MIXED LAYER

In near-surface layers of the ocean a mixed layer is produced by mechanical (turbulent) mixing induced by wind and by thermal or thermohaline convection induced by evaporation and sensible heat loss. The mixed layer exists during the greater part of the year and is usually shallowest in spring and summer months during the time of heat absorption by the ocean. During this period, the convective mixed layer may reach 20 to 30 meters at night and disappear after sunrise owing to local heat gain by the water.**

After the time of maximum surface temperature (about 20 August) the loss of heat overbalances the daily heat gain, and the mixed layer subsequently becomes permanent and deepens as convection proceeds. The maximum depth of convection is dependent on local water mass characteristics but usually reaches 700 to 1,000 feet. Unfortunately, the climatology of the mixed layer cannot be followed after about 1 December, because existing data at depths below 400 feet are still too sparse. However, in approximately 5 years as data from greater depths become available, the climatology of the mixed layer may be delineated from start to finish at specified locations.

The mixed layer constitutes part, but not all, of the layer above the thermocline. Strictly speaking, the top of the thermocline is nearly coincident with the level of maximum sound velocity (layer depth). Within the layer between the top of the thermocline and the surface, the mixed layer is usually clearly marked by isothermal BT traces or by complete thermohaline mixing in a nansen cast. The distinction between the bottom of the mixed layer and the top of the thermocline must always be kept in mind, because it complicates the prediction of the thermal structure.

V. THE TOP OF THE THERMOCLINE

As stated above, the top of the thermocline is not necessarily synonymous with the bottom of the mixed layer but is more nearly coincident with the level of maximum sound velocity. The top of the thermocline rises from some depth between 100 and 200 feet at the time of formation in May until a minimum depth is reached approximately the end of July. This minimum depth may range from near the surface to about 20 meters, thus expressing the level of nocturnal convection in midsummer.

**U. S. Naval Oceanographic Office. Diurnal Temperature Changes at Ocean Station ECHO - September 1959, by E. L. Corton. Technical Report No. 132, ASWEPS Report No. 9, June 1962.

The surface water temperature rises for approximately 3 weeks after the minimum depth of the top of the thermocline has been reached. The cause of this phenomenon may be increased mechanical mixing due to the hurricane season or may be increased nocturnal convection produced by the progressively longer time between sunset and sunrise which is overcome in daylight by the heat absorbed in the water.

By the end of August or early September, the top of the thermocline is nearly coincident with the bottom of the convectively mixed layer, and it is the mechanism of convection that drives the top of the thermocline downward thereafter and finally extinguishes the thermocline entirely.

VI. THE BOTTOM OF THE THERMOCLINE

As a physical entity, the bottom of the thermocline can be recognized by the change in gradient between the thermocline and the layer beneath. The bottom of the thermocline usually falls throughout the lifetime of the seasonal thermocline at a rate of about 20 feet per month. This increase in depth is probably due to eddy diffusion of heat through the bottom of the thermocline. Because the change in gradient at the bottom of the thermocline is not as extreme as the change in gradient at the top, the change in depth does not take much energy to accomplish. The diffusion of heat through the thermocline produces a slow rise of temperature below the thermocline which may affect the first 100 feet below the bottom of the thermocline. This heating is halted by heat loss when the convectively-mixed layer reaches below the thermocline in late fall and winter.

Heating below the thermocline is also accomplished through advection of heat (no examples have been noted where heat was lost due to advection, perhaps because ships do not stay long in areas where ice is found). Advection produced by warm currents is most marked in areas affected by the Gulf Stream and its extensions, but can also be seen at most places, even those far removed from the main currents. Vertical heat loss generally overbalances horizontal heat flux during winter months. The compensating mechanism to replace the vertical heat loss in winter months is horizontal advection of heat in summer months.

VII. TEMPERATURE AT 400 FEET

The annual cycle of temperature at 400 feet is the resultant of the forces of winter heat loss and summer heat gain. In the absence of advection, the temperature at 400 feet is controlled by the depth of convection. The temperature is always lowest at the time when the convective layer is deepest; maximum temperature at 400 feet is found just prior to the time when convection in the fall reaches 400 feet. This maximum temperature will be only slightly higher than that at the time of formation of the seasonal thermocline, since the only mechanism for increasing the temperature at 400 feet is eddy conduction through the bottom of the thermocline (in the absence of advection).

Advection below the thermocline raises the annual temperature range at 400 feet due to the increased temperature rise below the thermocline. However, the maximum temperature remains at the time when convection reaches 400 feet in autumn months.

VIII. CLIMATOLOGY -- THE MISSING PART

From the discussion above, the climatology of the thermal structure of the ocean would appear to be well understood by examples from the ocean station locations. A great portion of the climatology, however, is missing. This portion is that included under the broad title of "Variation".

One of the goals of the Naval Oceanographic Offices's repeated experiments (to date, 11 in the Atlantic and 5 in the Pacific) at ocean stations has been to acquire data concerning variability of the environment. In order to describe the environment completely, not only the normal state of the thermal structure (its climatology) but the variability around this normal value must be known. In other terms, a knowledge of "persistence" and "anomalies" is required.

Persistence is used here to denote the tendency of any disturbance in a fluid to continue for a time and then gradually die out due to the applicability of Newton's first law of motion. When the persistence factor is known, the probability that normality will resume after a given time interval can be predicted. An anomaly is described as the difference between an observed state of the fluid and the normal state of the fluid. Anomalies can be described as negative or positive, and large or small, when and only when the normal state of the environment is known.

In regard to both persistence and anomalies, the range and variability of environmental states must be investigated. The entire time spectrum from minutes to years should be included. The complete climatology states the probability of an hourly (daily, monthly, weekly, seasonal, or yearly) mean value of the parameter of the thermal structure departing by a given amount from the normal mean value.

The variability of the environment is not generally known, because years of regular observations are required to produce the necessary statistics. Indeed, the error of the mean of the surface temperature (the best known parameter of the ocean) is about $0.5^{\circ}F$. That is, even at the ocean stations, we do not know the normal surface water temperature at any time to within 0.5°F. As an illustration, mean temperatures at 5-day intervals at OWS DELTA (44°N, 41°W) were computed from about 1,700 BT's taken within the 5-year period 1950 through 1954. Some time thereafter, a compilation was made using about 7,000 BT's from all years 1944-1961; and more recently one using about 10,000 BT's. All three compilations differed from one another, and most shocking was the fact that the compilations made from the greatest numbers of observations differed in mean value by an average of 1°F. Consequently, at the present time we do not feel certain of the mean daily temperature for any weather ship within a margin of at least 0.5°F. The gap between this present knowledge (or lack of knowledge) and the necessary and vital requirement to be able to look at an existing observation and know how greatly it differs from normal is too obvious to require comment.

IX. CONCLUSION

This report describes a model of the climatology of the thermal structure at a single station. Knowledge of the cycle of formation, growth, and decay of the seasonal layer is incomplete owing to lack of temperature data below 400 feet. Some aspects of the isotherms at surface and subsurface levels are described. Finally, the unknown variability of the environment and the dual aspects of persistence and anomalies are listed.

In addition to this report describing single-station climatology, another report describing synoptic climatology is required. The additional study should postulate the climatological effect of the thermal patterns and current structure of the ocean as described by Gibson*** and other ASWEPS reports. The required climatological model for the synoptic ocean has not been constructed and may not be completed for some years. Because observations and analyses are subject to errors, some averaging processes must be applied; however, the nature of these processes has not been determined.

***U. S. Naval Oceanographic Office. Sea Surface Temperature Synoptic Analysis, by B. W. Gibson. Technical Report No. 70, ASWEPS Report No. 7, April 1962

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